Assessment of drought and heat coupling during summer using copulas

*Ana Russo [1], Andreia F. S. Ribeiro [1], Célia M. Gouveia [1,2] and Carlos Pires [1]

* acrusso@fc.ul.pt; [1] Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Portugal; [2]Instituto Português do Mar e da Atmosfera (IPMA), Lisboa – Portugal

1. Motivation

Droughts and hot extremes constitute key sources of risk to several socio-economic activities and human lives throughout the world, and their impacts can be exacerbated by their co-occurrence **[1]**. Moreover, their occurrence is expected to increase under future global warming **[2]**.

Here, we propose to analyze if the occurrence of summer extremely hot days in the Iberian Peninsula (IP) is preceded by the occurrence of drought events in spring and early summer.

2. Data

- Drought events characterized by the Standardized Precipitation Evaporation Index (SPEI) **[3]** for May, June and July for different timescales (3-, 6- and 9-months).
- Summer hot extremes characterized by the Number of Hot Days (NHD) **[4],** defined as the number of days with maximum temperature exceeding the 90th percentile, summed over July and August.

3. Methods

Cluster and Principal Component Analysis (PCA)

6 different clusters are identified and spatial averages of SPEI and NHD were computed (**Fig. 1 a**).

→ **Probability of extremely hot days preceded by drought**

Calculation of the joint probability distribution through copula theory **[5,6,7]**.

Copula Fitting

Among Normal, t, Clayton, Frank, Gumbel and Joe copulas the model selection is performed based on the Bayesian information criterion (BIC).

→ **Evaluation**

Correlation examined in terms of the Kendall's τ .

Upper tail dependence λ_U based on parametric estimator θ by

$\lambda_U = 2 - 2^{\frac{1}{\theta}}$ **[6]**

Risk assessment

Copula-based samples of NHD under: i) drought (SPEI <= -0.84) and ii) normal/wet conditions (SPEI > -0.84) **[7]** used to obtain the conditional survival functions 1-$Fv_{sim,dry}$ and 1-$Fv_{sim,wet}$ (**Fig. 2**)

→ **Conditional Probability**

Extreme summers identified by conditional probability of exceeding the NHD 80th percentile for: i) 1-$Fv_{sim,dry}$ (0.8) (drought) and ii)1-$Fv_{sim,wet}$ (0.8) (wet/normal)

4. Results

a) Iberian Peninsula regions

Fig. 1 – a) Iberian Peninsula drought regions: northwestern (NW), northeastern (NE), central (C), western (W), southwestern (SW) and southeastern (SE).

Dependence increases with the co-occurrence of SPEI and NHD (τ increases from May to July **Fig. 1 b**) and NE exhibits the strongest τ (almost all months and timescales)

b) Kendall correlation τ

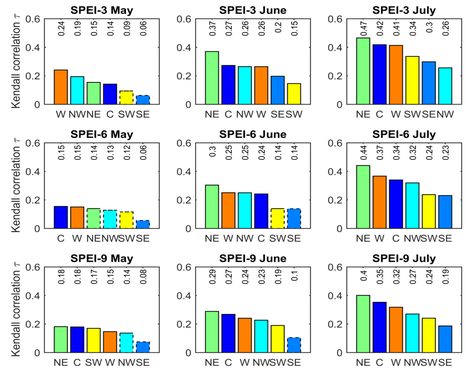

Fig. 1 b) Kendall's correlation coefficient (τ) between SPEI (3-, 6- and 9-months) in May, June and July and the sum of NHD in July and August (1950-2014) over each regions. Bars displayed in descending order of τ values. Dashed lines indicate regions failed the dependence test (p-value > 0.1, Kendall's τ)

Most of the regions are dominated by upper tail dependence (**Fig. 1c**). NW is only characterized by symmetric dependence.

c) Upper tail dependence λ_U

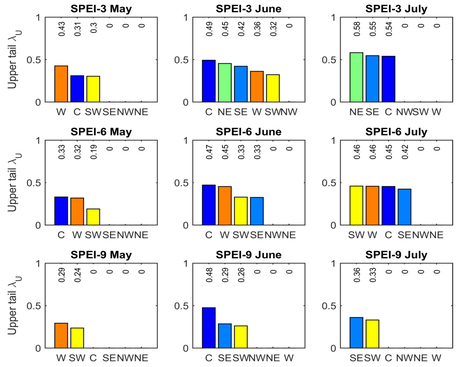

Fig. 1 c) Upper tail dependence parameter (λ_U) based on the selected copulas. The cases characterized by copula models without upper tail dependence features λ_U =0 (Normal and Frank copulas).

Dryness on previous months (rather than **normal/wet** conditions) seems to rise the conditional probabilities of occurring hot extremes in the following summer (**Fig. 3a**)

Summer hot extremes may be induced by previous soil moisture deficits, as shown by the increasing probability of exceeding NHD extreme values when SPEI shifts from previous **wet** to **dry** regimes (**Fig. 2 and 3**).

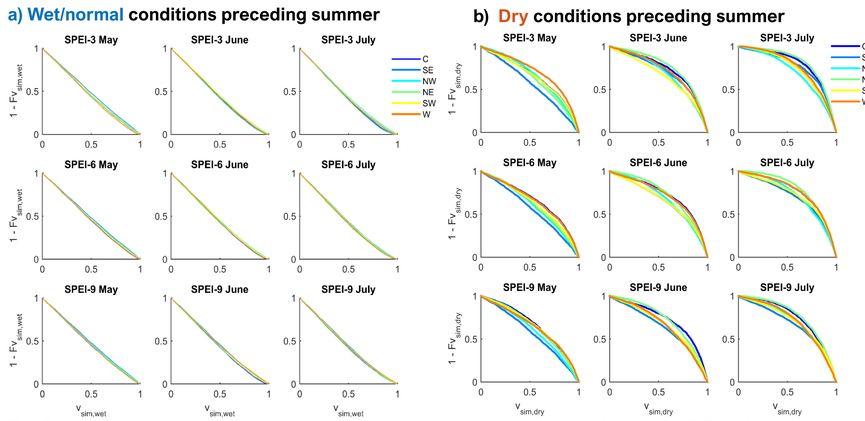

Fig. 2 – a) Conditional survival curves based on the copula-based samples of summer NHD under **wet/normal** conditions conditions ($v_{sim,wet}$), indicating the exceedance probability 1-$Fv_{sim,wet}$ and b) **dry** conditions.

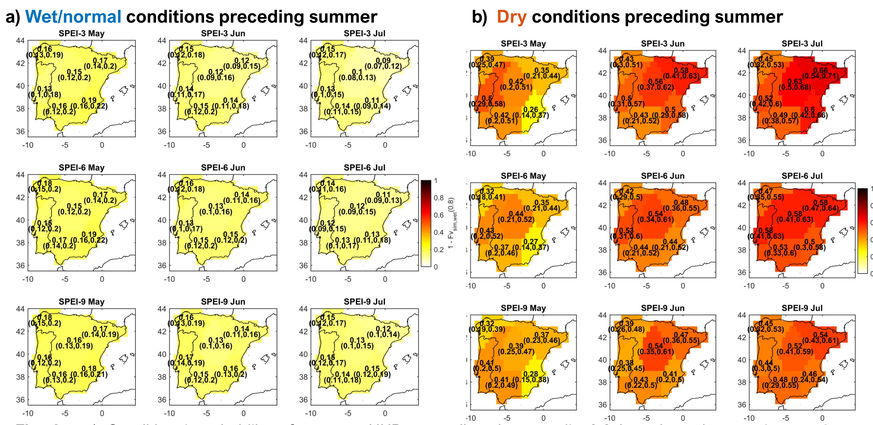

Fig. 3 – a) Conditional probability of summer NHD exceeding the quantile 0.8 based on the copula samples over drought regions preceded by **wet/normal** conditions (1-$Fv_{sim,wet}$(0.8)) and b) **dry** conditions (1-$Fv_{sim,dry}$(0.8)).

In general, NE, W and C regions are the regions with highest conditional probabilities of exceedance of hot extremes preceded by **dryness**, in contrast to SW, NW and SE regions (depending on the SPEI month and timescale) (**Fig. 3 b).**

5. Conclusions

- The dependence between SPEI and NHD is very well identified for the most of the IP's regions by upper tail dependence (except in NW region)
- The transition from previous wet to dry regimes increases substantially the probability of exceeding summer hot extremes
- Drought spatial heterogeneity was found to be a main factor when characterizing the water stress influence on following summer extreme temperatures

REFERENCES

[1] Seneviratne SI et al., 2010, https://doi.org/10.1016/j.earscirev.2010.02.004; **[2]** IPCC 2012; **[3]** Vicente-Serrano SM et al., 2010. https://doi.org/10.1175/2009JCLI2909.1; **[4]** Expert Team on Climate Change Detection and Indices (ETCCDI) (https://www.wcrp-climate.org/etccdi, http://etccdi.pacificclimate.org/index.shtml; **[5]** Durante and Sempi 2015, https://doi.org/10.1201/b18674; **[6]** Nelsen 2006, https://doi.org/10.1017/CBO9781107415324.004; **[7]** Salvadori and De Michele 2007, https://doi.org/10.1061/(ASCE)1084-0699(2007)12:4(369)

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